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Photovoltaic systems in school units of Greece and their consequences

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ABSTRACT

The increase of greenhouse gases has lead to climate change. This has a serious impact on the ecological balance of the planet. A decisive step in order to address this problem is to implement the use of renewable energy sources (RES) such as solar, aeolian, geothermal and other forms of energy.

This study refers to the installations of photovoltaic systems in school units within the framework of national existing legislation and European Union (EU) directives. The case study that has been chosen in this report is the school units in Greece which has had operating photovoltaic systems installed.

More specifically the research focuses on the benefits arising from the use of photovoltaic systems showing to what degree they can contribute to reducing greenhouse gases.

The survey shows that the installation of photovoltaic systems in schools units contributes greatly to saving energy, reducing costs for energy consumption, protecting natural sources and thereby has a favourable effect on climate change mitigation. On the other hand, the research also shows that potentially windy areas should be preferred to invest in construction of aeolian parks, where it is possible, rather than installing photovoltaic systems in school units.

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1. Introduction

Environmental degradation and the threat to human existence make it necessary to take measures for protection. One of these measures is promoting the use of renewable energy sources (RES).

The increase rate in electricity production from RES comes at the top of the list in the Kyoto Protocol [1] for climate change. The European Union, the first one to commit itself to action in this field and sign the Protocol, has adjusted its policy, and, according to the EU's White Paper, the production of electricity from renewable sources is a high priority [2].

The objectives of the EU are:

- According to the road map [3], the RES must cover 20% of the total energy consumption in the EU in the fields of electricity, biofuels, heating and cooling by 2020.
- According to EU Directive 2001/77/EC [4], 22.1% of total electricity consumption must come from RES by 2010.
- According to the European Union Council, greenhouse gas emissions must be reduced by at least 20% in 2020 in comparison to their 1990 levels [1].

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For Greece, in accordance with national objectives, the share of RES in gross electricity consumption should rise up to 20.1% in 2010 and to 29% by 2020 [5]. Greece also commits itself to limiting the increase of emissions by 25% for the period 2008–2012 [6].

RES projects are described as public utilities which contribute to protect the environment and guarantee the safety of energy production in the country [7].

Taking the above guidelines into account, and thanks to the country's climatic conditions, great progress has been made in Greece in the installation of photovoltaic systems and wind turbines. In March 2010, out of a total of 19,105.60 MW in electricity production, 7429,19 MW come from wind parks, 472.84 MW come from photovoltaic systems, 97.07 MW come from biomass, 8 MW come from geothermal and 799.91 MW come from hydroelectric projects [8].

By law for the penetration of photovoltaic systems into the production of electricity, their installation has been extended to school units in order to cover the schools' energy needs.

As will be shown below, due to the large number of schools and their energy requirements, the installation of PV systems in school units has turned out to be one of the main actions in addressing the climate change issue.

This research focuses on the rate at which school units can contribute to save energy and reduce CO_2 emissions by installing PV systems on school roofs.

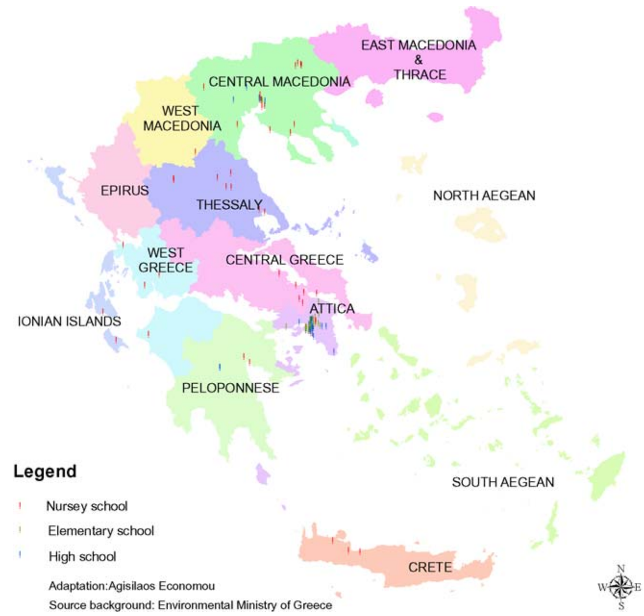

Fig. 1. School units in Greece with PV systems.

2. Data and methods

The research is based on school unit statistics at national level. It relies on programmes evaluating the electricity production via PV such as the photovoltaic geographic information system (PVGIS) in different regions of Greece, as well as on American forests' programmes which evaluate the avoidance of carbon dioxide emissions.

The survey also includes personal interviews with relevant staff of the School Building Organization (SBO) in Greece, the organization which is responsible for the installation of PV systems in school buildings.

The financial and environmental benefits have been estimated on the basis of these results and have further been compared with similar benefits in aeolian production of electricity (wind turbines).

3. Case study (Greece)

As mentioned above, the extended implementation of RES, has led the School Buildings Organization (SBO) to plan the installation of PV systems in new schools as well as in the existing ones.

At a national level PV systems have been installed in 82 school units with a total power of 828.58 kWp (Fig. 1).

The largest number of schools with PV systems is located in the Attica region (Fig. 2).

The 7th High School of Piraeus was selected as a case study, the first school where the system of photovoltaic systems is connected to the electricity network of the National Board of Electricity.

The school building is located in Piraeus (Fig. 2) and has a total area of 710 m^2. On an area covering 647 m^2 of its roof, there are 108 panels (Shuuco SPV 180-SMG-S) with a size panel ($0.81\ m \times 1.58\ m$) that cover an area of 138.2 m^2 and 30% inclination. The total power installed is 19.44 kWp. The photovoltaic panels are made of crystalline silicon [9].

4. Results

Performance of the PV systems installed on the roof of the 7th High School of Piraeus (Figs. 3 and 4).

The SBO research is based on personal interviews and statistical data and shows that:

- The installation of PV systems in school units in Greece started in late 2004 and currently continues at an increasing rate.
- In high school units, a production of up to 20 kWp power is being installed. Additional power capacity involves an increase in costs and services.
- To date, photovoltaic systems have been installed in 82 schools in 26 prefectures. Specifically, PV systems are installed in 42 nursery schools, 16 secondary schools and 23 high schools, generating a total of 828,58 kWp. Of these, only one school is connected to the low voltage network of the National Board of Electricity. The remaining schools will be connected as soon as all bureaucratic procedures have been completed.

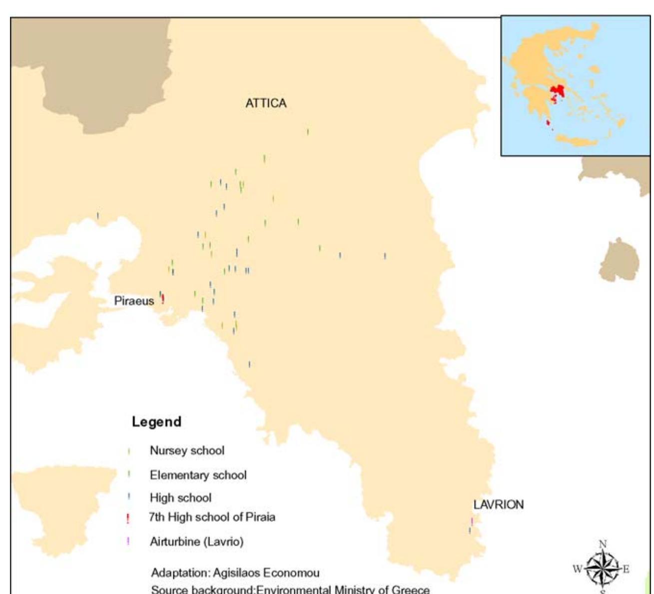

Fig. 2. PV systems in school units in Attica.

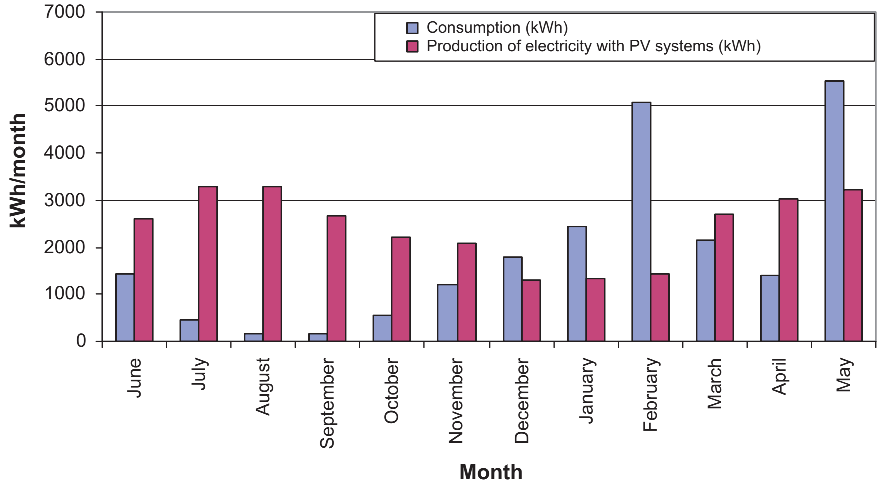

Fig. 3. Consumption and production of electricity with PV systems in the 7th High School of Piraeus [10,11].

- On paper, though not yet in practice, there are another 8 nursery schools, 4 secondary schools, 5 high schools and 2 areas with sports facilities.
- Taking into account that the installation of 1 kWp costs 4500 euro, a total sum of 3,728,610.00 euro has been invested so far (excluding VAT).

5. Discussion

5.1. Energy needs in school buildings

5.1.1. 7th High School of Piraeus

From the diagram (Figs. 3 and 4) we conclude that the consumption of electricity is higher in February and March because of the use of headlights in school units during the night.

Also, the electricity that is consumed by schools during the examinations periods is greater than the PV system production, as it is during the winter months when the production of PV systems is reduced due to weather conditions.

In the period spanning June 2008 to May 2009, the photovoltaic system at the 7th High School of Piraeus yielded 29,131.56 kWh and consumed 22,357 kWh [11]. That is to say, it not only completely covers the electricity needs of the school unit, but it adds a benefit of 29,131.56 − 22,357 kWh = 6774.56 kWh per year.

Taking into account the installation cost of the PV systems at the 7th High School of Piraeus, 19.44 × 4500 = 87,480, the maintenance cost 1–2% of the installation cost [13] (2% × 87,480 = 1749,6 euro/year), and the income gained from the system, 29,131.56 × 0.457 euro = 13,313.12 euro, it is estimated that the installation costs of the photovoltaic cells will be covered in 7.5 years, assuming that production per year remains stable.

5.2. Other school units

To evaluate the energy required to cover a school's needs in electricity depends on the needs of the school building and the overall power of the photovoltaic installation.

For example, at the 6th Nursery School in Paleo Faliro (passive solar school equipped with energy saving systems), it has needed 15,504 kWh of electric energy for its 500 m^2 in the year 2009.

The installation of photovoltaic (PV) systems with a total power of 6 kWp, will yield 1340 kWh/year × 6 = 8040 kWh per year, thereby covering half the needs of the school building (Fig. 5).

- Power of the PV system: 1.0 kW (crystalline silicon)
- Estimated losses due to temperature: 10.5% (using local ambient temperature)
- Estimated loss due to angular reflectance effects: 2.6%
- Other losses (cables, inverter etc.): 14.0%
- Combined PV system losses: 25.0%
- Inclination Panel 30%

On the other hand, in small nursery school units of less than 250 m^2, the installation of 5.1 kWp fully covers the energy needs for electricity.

The performance of PV in the geographical area of Greece depends on longitude and latitude and on weather conditions. The following table shows the number of schools by region and the performance of 1 kWp (Table 1).

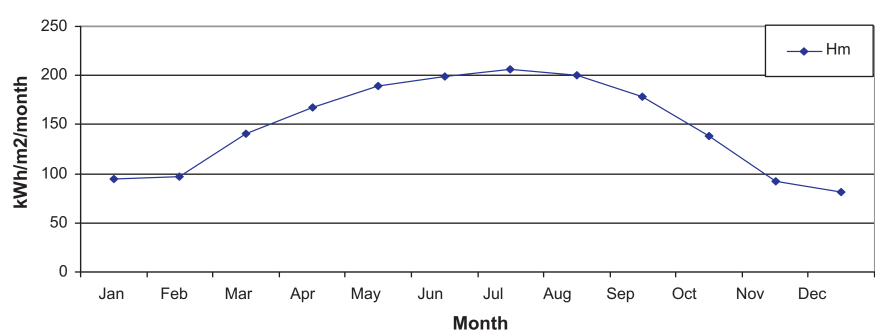

Fig. 4. Hm: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2) [12].

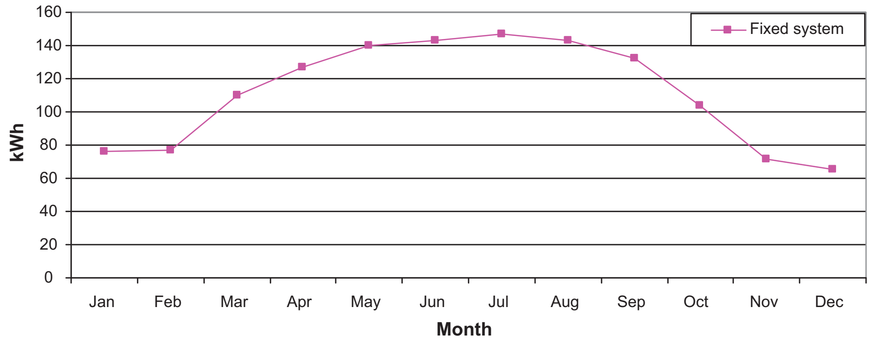

Fig. 5. Average monthly electricity production from the given system (kWh) at the 6th Nursery School of Paleo Faliro [12].

Moreover, from the table above it is clear that the performance of PV varies from region to region. We have photovoltaic systems with a total power production of 5.1 kWp in nursery school units and 20 kWp in secondary schools and high schools to cover the needs of all school units 211.72 MWp are required at national level.

Based on the performance of PV systems per region and the corresponding number of schools, the average performance of PV systems would be 260,79 MWh per year in all school units.

5.3. Environmental benefits

Solar energy is a source of clean energy and can be used without generating pollution [15].

According to the data on electricity production with PV systems at the 7th High School of Piraeus, it is clear that the main environmental gain derived from the production of 2,9131.56 kWh, results in the reduction of carbon dioxide (CO_2) emission of 21.8 tons of CO_2, which is equivalent to 66 trees that would be needed for its absorption. Similarly, the 82 PV units which were mentioned above, for which the electricity production is estimated at 129,930 kWh/year (inclination 30%) correspond to a reduction of 97.4 tons of CO_2, equivalent to 293 trees for its absorption [16].

6. Comparing the performance of photovoltaic systems to wind turbines in the region of Attica

The efficiency of wind turbines in Greece has also been estimated. A good case study is the aeolian park in the area of Lavrion. It includes 5 air turbines generating a total power of 3.01 MW, equivalent to 4.1 million euros. The aeolian park was funded by the Second Community Support Framework (CSF) within the Environmental Performance Evaluation framework (EPE) [17].

The CRES statistics show that a wind generator of 500 kW (total wings surface (m^2) = 1735, rotor diameter = 44, hud height = 44 m, number of blades = 3 m), during a year with wind potential 6.9 m/s, is yielding 1.06 MW [17].

A typical air turbine powered at 1 MW (hud height = 65 m, number of blades = 3, rotor diameter = 60 m) in the region of the aeolian park of Laurion, is yielding 2.58 MWh, with a load factor of 28% and with an annual mean wind speed (6.9 m/s) (Table 2) [18].

Taking into account the cost of installation (1.3 million euros), the maintenance cost 12% of production = 141,458.738 and profits from the production of electricity 2,579,481 $\times$ 0.457 kWh = 1,178,822.817 the total economic benefit is equivalent to 1,037,364.07 euro per year. While the environmental benefit consists in the reduction of 1934.6 tons of CO_2, equivalent to 5804 trees needed for its absorption.

Compared with photovoltaic systems in the region of Attica (Lavrion) we have:

In relation to wind turbines, photovoltaic systems cost more and generate less electricity (Table 3). For the Athens area we have cost of installation (1 MW) PV systems/cost of installation (1 MW) wind turbine = 1.3 million euro/4.5 million euro = 0.28. That means that, compared to wind turbines, the cost will be three times more and electricity production will be less, if we invest in photovoltaic systems with equal power production rate.

Acknowledging the fact that photovoltaic installations are made with money from the Greek government, we conclude that the installation of photovoltaic systems in schools in areas with low wind potential and high sunshine is financially profitable. Moreover, since schools are in residential areas, restricted areas and other areas of limited land use, there are restrictions for the

Table 1
Number of public schools in Greece during period 2005–2006 and electricity production energy with a 1 kWp power installation per region [14].

Region	Nursery schools	Secondary	High school	Total	Annual PV power (kWh/1 kWp) (optimal) (average mean)
East Macedonia & Thrace	358	291	193	842	1115
Central Macedonia	1030	857	577	2464	1115
West Macedonia	247	235	135	617	1165
Thessaly	567	552	290	1409	1166
Epirus	268	273	166	707	1172
Ionian islands	154	124	98	376	1175
West Greece	451	543	280	1274	1242
Central Greece	355	402	243	1000	1256
Peloponnese	366	377	247	990	1256
Attica	1037	1051	948	3036	1309
North Aegean	158	164	112	434	1311
South Aegean	210	203	179	592	1315
Crete	428	404	207	1039	1352
Total	5629	5476	3675	14,780	

Table 2
Wind speed and corresponding output power from a standard air turbine in the Lavrion area [18].

Months	(m/s)	Production (1 MW) (kWh)
June	4.73	94,223
July	8.92	347,069
August	7.26	249,674
September	7.49	245,563
October	5.32	120,799
November	6.84	219,329
December	8.43	315,106
January	8.1	282,612
February	7.99	242,405
March	6.49	188,085
April	5.81	145,820
May	5.19	128,797
Total		2,579,481
Average	6.9	

Table 3
Installation cost of 1 PV system and wind turbine with a total power of 1 MW.

	Photovoltaic systems	Wind turbine
Power (MW)	1	1
Cost (euro)	4,500,000	1,300,000
Production (GWh/year)	1.35	2.58
Maintenance cost	90,000	141,458.738
Financial benefit (euro)	526,950	1,037,364.07
Annual reduction of CO_2 emissions (tons)	1012.5	1934.6
Annual number of new trees that would be needed for the absorption of CO_2	3037.5	5803.8

installation of wind turbines. Thus, the investment and implementation of PV systems in schools is a better choice.

Furthermore, the participation of private investment for the installation on school roofs can further increase the income of School Committees (who are responsible for the handling of the school buildings finances) and reduce the emission of greenhouse gases due to electricity production.

Today at a national level the installation of PV systems in school units shows an increasing trend that will continue for the next years. The goal is not to install PV systems in all schools, but in those capable of contributing to the production of electricity energy according to the needs and possibilities of each region.

On the other hand, in potentially windy areas, investing in aeolian parks (at a regional level) compared with PV systems in school buildings, would result in the production of more electricity at a lower cost and extended financial and environmental benefits.

7. Conclusions

We conclude from the above that the policy to install photovoltaic systems on school roofs is an important contributing factor in our programme against climate change, due to the exploitation of renewable sources for energy production which successfully side-step the avoidance of the production and emission of CO_2 into the atmosphere.

The survey shows that in large school buildings, the installation for the power production of 20 kW in photovoltaic systems does not adequately cover all the building's needs, unlike small schools where the installation of 5.1 MW fully covers the energy needs. This creates the need for greater installations, according to the requirements in each school and despite the obstacles.

In significantly windy areas with a large potential, the construction of aeolian parks wherever possible is a better investment, regardless of any photovoltaic system installation in schools of the area. This is because, as demonstrated above, aeolian parks provide much greater profits and particularly in a greater time span of 20–25 years.

References

[1] Commission of the European Communities. Council decision of 25 April 2002 concerning the approval, on behalf of the European Community, of the Kyoto Protocol to the United Nations Framework Convention on Climate Change and the joint fulfilment of commitments thereunder, OJ L 130, Brussels; 2002. p. 1–3.
[2] Commission of the European Communities. Resolution on the commission communication: energy for the future: renewable sources of energy—white paper for a community strategy and action plan, OJ C 210, Brussels; 1998. p. 215.
[3] Commission of the European Communities. Communication from the commission to the council and the European parliament, Renewable Energy Road Map. Renewable energies in the 21st century: building a more sustainable future, COM (2006) 848 final, Brussels; 2007. p. 1–20.
[4] Commission of the European Communities. Directive 2001/77/EC of the European Parliament and of the council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market, OJ L 283, Brussels; 2001. p. 33–40.
[5] Official Journal of the Hellenic Republic. 129/A/27.06.2006; 2006. p. 1405–26. http://www.et.gr/search_publication.
[6] Official Journal of the Hellenic Republic. 2464/B/03.12.2007; 2007. p. 35207–40. http://www.et.gr/search_publication.
[7] Official Journal of the Hellenic Republic. 2464/B/03.12.2008, p. 35207–35240.
[8] Regulatory Authority of Energy (RAE). Statistics data, Athens; 2010. http://www.cres.gr.
[9] SBO (School Building Organization S.A.). Description—specifications photovoltaic installations at 7th High School of Piraeus, Athens; 2008. p. 1–13.
[10] Public Power Corporation S.A. Electricity consumption in area of Athens, Athens; 2010.
[11] http://www.sunnyportal.com/Templates/PublicPagesPlantList.aspx.
[12] http://re.jrc.ec.europa.eu/pvgis/apps3/pvest.php.
[13] Center for Renewable Energy Sources (CRES). Information about PV systems, Athens; 2009. http://www.cres.gr/kape/PV_INFO.pdf.
[14] Centre for Educational Research, Statistics School Data Units 2005–2006, Athens; 2007.
[15] Moraes Toledo O, Oliveira Filho D, Sonia Alves Cardoso Diniz A. Distributed photovoltaic generation and energy storage systems: a review. Journal of Renewable and Sustainable Energy Reviews 2010;14:506–11. doi: 10.1016/j.rser.2009.08.007.
[16] http://www.americanforest.org/resources/ccc/.
[17] http://www.creswindfarm.gr/site1/index.htm.
[18] Center for Renewable Energy Sources (CRES). Statistical Data of Aeolian park in the area of Lavrion, Athens; 2010. http://www.creswindfarm.gr.